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Waterways Experiment Station

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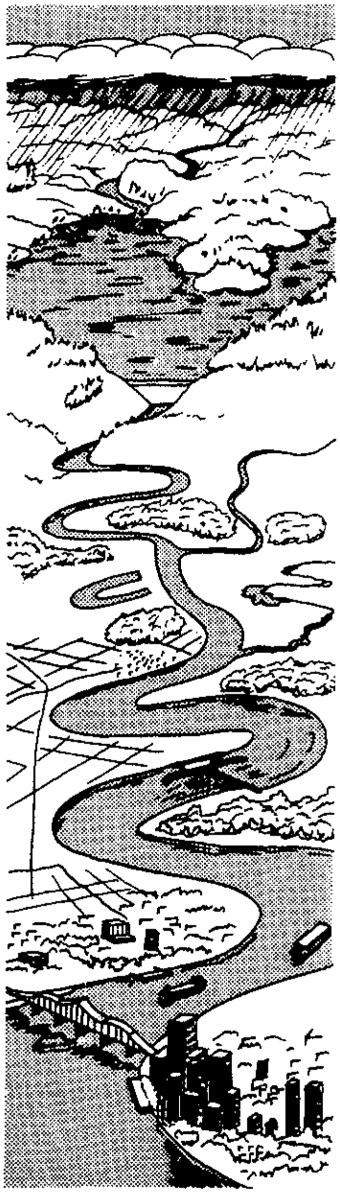

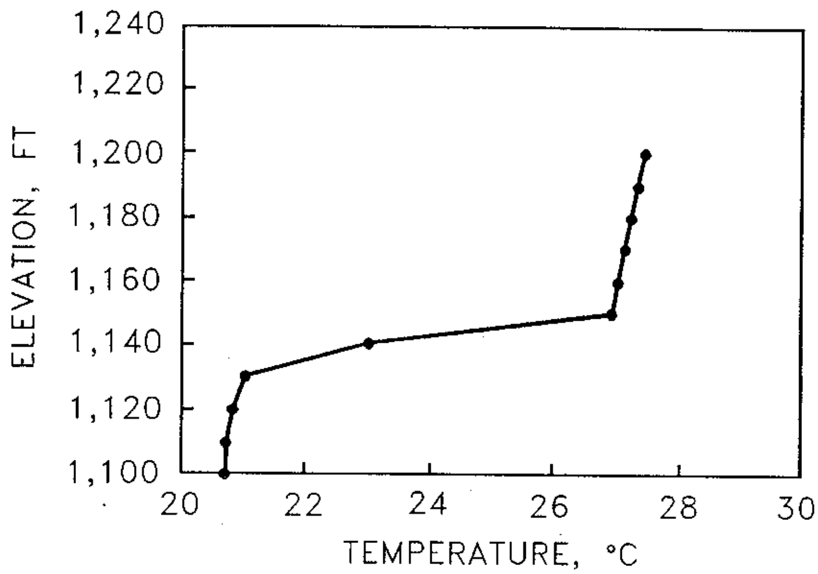

Figure 1. Example temperature profile

Evaluating Commercially Available Destratification Devices

by

Richard E. Price
Hydraulics Laboratory
US Army Engineer Waterways Experiment Station

The thermal stratification that occurs in most US Army Corps of Engineers (USACE) reservoirs is a potential water quality problem for reservoir managers. Thermal stratification effectively isolates the hypolimnion from circulation with the surface water. Through normal biochemical and respiratory processes, the rate of oxygen utilization in the hypolimnion may exceed the rate of dispersion from upper reservoir layers, creating an anoxic zone. An anoxic condition in the hypolimnion is undesirable because it may decrease the biological productivity by releasing iron, manganese, and hydrogen sulfide. Also, if a release structure withdraws water from this zone, significant levels of iron, manganese, and hydrogen sulfide as well as low dissolved oxygen (DO) water may be released downstream.

A variety of techniques may be used to alleviate these anoxic conditions in the hypolimnion, including destratifi-

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cation or reaeration techniques. Destratification techniques prevent thermal stratification and allow circulation of the entire water column to the surface for reaeration. Reaeration techniques add oxygen to the water column without disturbing the thermal stratification. Additional information on these techniques may be found in Pastorok, Lorenzen, and Ginn (1982), Bohac and others (1983), and Holland and Tate (1984).

A variety of mechanical or pneumatic devices, many commercially available, may be used for destratification. In a previous article (Price 1988), commercially available axial flow pumps and direct drive mixers which could be used as destratification systems were described. This article introduces methods to evaluate the performance of commercially available hydraulic mixers for destratification of reservoirs.

Destratification Pumps

Existing design guidance for destratification using hydraulic pumps was mostly developed for determining whether a reservoir could be destratified (Holland and Dortch 1984). If this existing guidance indicates that destratification is feasible, a pump system can be designed. Two types of pumps may be suited for these applications—axial flow pumps and direct drive mixers. An axial flow pump usually has a large-diameter (6- to 15-foot) propeller which rotates at a slow speed and generates a low-velocity jet. A direct drive mixer has a small-diameter (1- to 2-foot) propeller, but rotates at a high speed and generates a high-velocity jet. Table 1 gives examples of these two types of pumps with various horsepower motors and various diameter propellers. Axial flow pumps generate much larger discharge, but at relatively low velocity and hence little momentum. Direct drive pumps generate a much smaller discharge, but at a relatively high velocity and hence add significant momentum to the jet.

Table 1
Comparison of Axial Flow and Direct Drive Pumps

Type of Pump	*Power horse-power*	*Jet Diameter feet*	*Discharge cubic feet per second*	*Jet Velocity*
Axial	3	6	75	2.8
	4	8	143	2.7
	30	15	600	3.0
Direct Drive	3	0.95	6.3	8.8
	10	1.2	16.9	14.9
	20	1.4	26.2	17.7
	40	1.7	45	21.9

Evaluation Method

Hydraulic destratification systems using pumps could be designed using criteria similar to that developed for pneumatic destratification devices. Pneumatic systems are designed to mix the reservoir volume in a relatively short period of time, usually 5 to 10 days (Davis 1980). If the same approach is taken in designing hydraulic destratification systems, the mixing time of the destratification device must be determined.

Mixing time may be defined as the time for complete homogenization of the basin, but is more appropriately expressed quantitatively as the recirculation of the basin volume per unit of time. Establishing the mixing time requires determining the flow rate of the pumping device. If the reservoir has a uniform temperature from top to bottom, then the mixing time could be expressed simply as the ratio of reservoir volume to pump flow rate. However, if thermal stratification exists, then a resistance to mixing due to the density differences between layers will exist. This resistance to mixing, sometimes defined as relative thermal resistance (Wetzel 1975), will resist and dissipate the momentum in the jet, reducing the depth to which the jet will penetrate. Therefore, the depth of penetration of a jet will be impacted by the stratification in the reservoir. The mixing time then becomes a function of the volume of epilimnetic water which passes through the thermocline, termed the epilimnetic volume flux, and into the hypolimnion. The ability to mix a given reservoir in a given timeframe depends on the stratification of the reservoir and its impacts on the depth of penetration of the jet and the volume flux at the thermocline, as well as the pump flow rate.

A hydraulic destratification system may be designed for a given reservoir stratification and depth using either axial flow pumps or direct drive mixers. The following evaluation method may be used to determine which pump to use.

First, determine the reservoir characteristics, such as maximum depth, lake volume, epilimnetic and hypolimnetic temperature at the start of the destratification process, and desired mixing time.

Determine the required depth of penetration of the hydraulic jet. This will usually be an elevation within several feet of the bottom. Next, select a pump which will achieve the required depth of penetration. The depth of penetration for a given pump can be computed using formulas given in the design guidance for localized mixing systems (Holland 1984).

Evaluate the epilimnetic volume flux generated by the pump as determined above, using the formulas given in Holland (1984).

Determine the number of pumps required to achieve the desired mixing time. This can be determined using a slight variation of a formula derived by Gu and Stefan (1988). This formula, which involves dividing the lake volume by the epilimnetic volume flux multiplied by 0.25, will yield the time to achieve a mixed condition in the lake. If this result is longer than the desired mixing time, the number of pumps should be increased to achieve the desired mixing time.

Application of Evaluation Method

To illustrate this evaluation method, the two types of pumps shown in Table 1 were evaluated for destratifying a reservoir, using an example stratification pattern for a USACE hydropower reservoir. The surface temperature for this reservoir was 27.4° Celsius (C) and the hypolimnetic temperature was 20.7° C with the thermocline at a depth of 52 feet, a total lake depth of 100 feet (Figure 1), and a total lake volume of 9,180 acre-feet. According to the procedure described above, the depth of penetration of the jet should be computed first. To completely destratify the lake, the jet needs to penetrate to the bottom without disturbing the sediment. The depth of penetration was computed using the formula developed by Garton as reported in Holland (1984) for the axial flow pumps and by Holland (1984) for the direct drive mixers. These results (Figure 2) indicated that the direct drive units produce a greater depth of penetration for the same horsepower as the axial flow pumps. Therefore, the 20-horsepower direct drive pump appears initially superior since it provides the depth of penetration required to reach the layers near the bottom.

The next step is to compute the epilimnetic volume flux generated by the pump. The formulas for computation of epilimnetic volume flux described were used to compute the volume flux for the 20-horsepower direct drive pump as 317 cubic feet per second.

Using the formula for computing the mixing time, the pump would mix the lake in approximately 3.6 days, which is acceptable.

This analysis was performed for a single stratification. However, as the lake is destratified, the volume flux and depth of penetration calculations should be repeated with successively weaker stratifications to estimate power requirements as well as prevent overpenetration and disturbance of the sediment. Additional stratifications which would cover a range of anticipated conditions for the reservoir should also be analyzed. For example, a shallower thermocline may significantly reduce the entrainment of the jet and reduce the epilimnetic volume flux and the mixing time.

The results of this evaluation indicate that for the deeper depth of penetration needed with the example lake, a direct drive pump was better

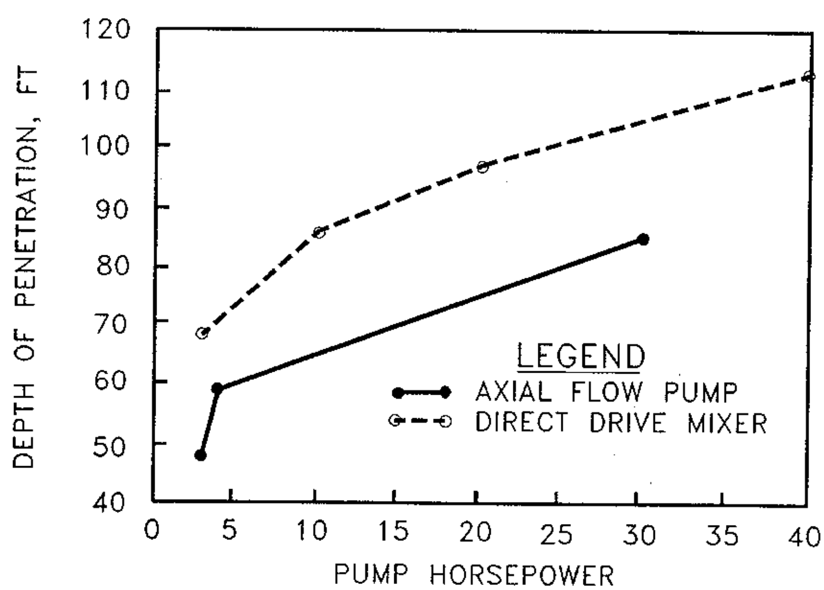

Figure 2. Depth of penetration for axial flow and direct drive pumps

suited that an axial flow pump. However, with a shallower lake requiring a pump penetration depth of 60 feet, a direct drive pump may not be the recommended type of pump. Using the method outlined above with the same lake characteristics and a reservoir depth of only 60 feet, a 4-horsepower axial flow pump would provide the required depth of penetration; the smallest horsepower direct drive pump from Table 1 would penetrate to the bottom and possibly disturb sediments (Figure 2). However, if the depth of the lake were 85 feet with the same profile as shown in Figure 1, the depth of penetration computations would indicate that either a 10-horsepower direct drive pump or a 30-horsepower axial flow pump would provide the required depth of penetration.

The evaluation method then requires the determination of the epilimnetic volume flux. The epilimnetic volume fluxes for both types of pumps were computed using the same stratification as shown in Figure 1, but using only the profile to a depth of 85 feet. The results of these computations are shown in Figure 3. For this example, the 30-horsepower axial flow pump generated 665 cubic feet per second epilimnetic volume flux, while the 10-horsepower direct drive pump generated 234 cubic feet per second epilimnetic volume flux. In terms of equivalent horsepower, three 10-horsepower direct drive pumps (30 horsepower total) would generate 702 cubic feet per second of epilimnetic volume flux; however, the difference between a system composed of a single axial flow pump and a system composed of three direct drive pumps may be insignificant. Although the direct drive pumps entrain more epilimnetic flow than the axial flow pumps, as shown in Figure 4, the axial flow pumps generate a larger volume flux per pump. Thus, with a reservoir depth of 85 feet, a 30-horsepower axial

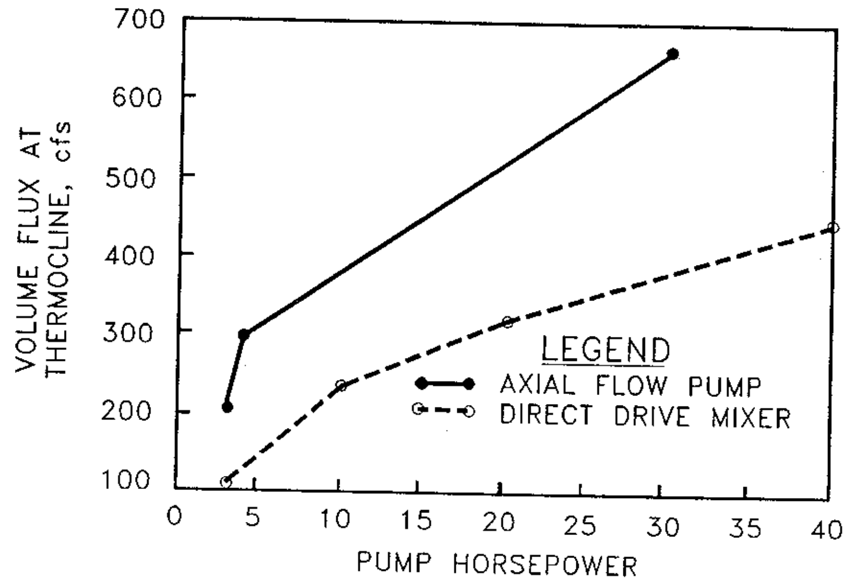

Figure 3. Comparison of volume flux of water across the thermocline for axial flow and direct drive pumps

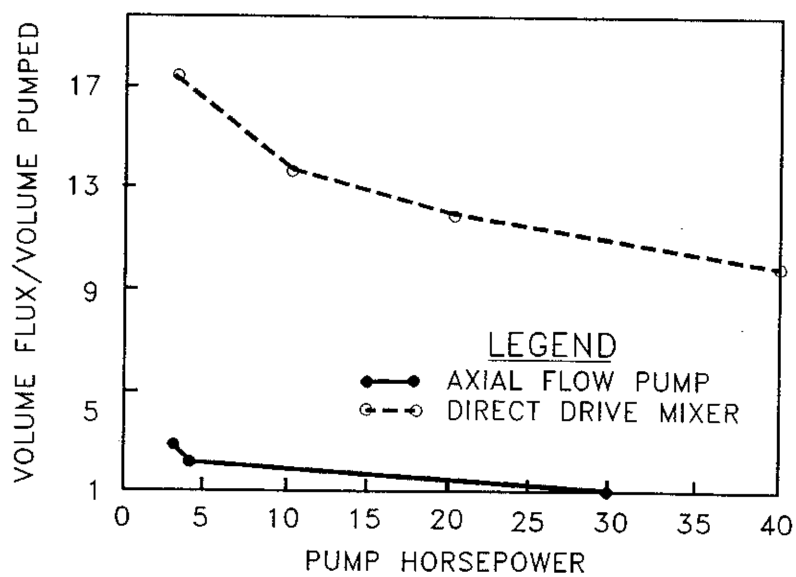

Figure 4. Comparison of entrained flow (epilimnetic volume flux/ pump flow rate) for axial flow and direct drive pumps

flow pump or three 10-horsepower direct drive pumps would provide the required depth of penetration and the epilimnetic volume flux (Figure 2). In this case, selection of a type of pump would be made on the basis of other factors such as availability, installation, or operational factors.

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RESEARCH PROGRAM

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LARRY B. FULTON
Colonel, Corps of Engineers
Commander and Director

Reservoir managers face a potential water quality problem resulting from thermal stratification which occurs in most Corps of Engineers reservoirs. Possible anoxic conditions in the hypolimnion may decrease the biological productivity of a reservoir by releasing iron manganese and hydrogen sulfide. In this issue methods are given for evaluating commercially available hydraulic mixers for destratifying reservoirs.

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WATERWAYS EXPERIMENT STATION, CORPS OF ENGINEERS
3909 HALLS FERRY ROAD
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